Illuminating the Dark Photon with DarkLight

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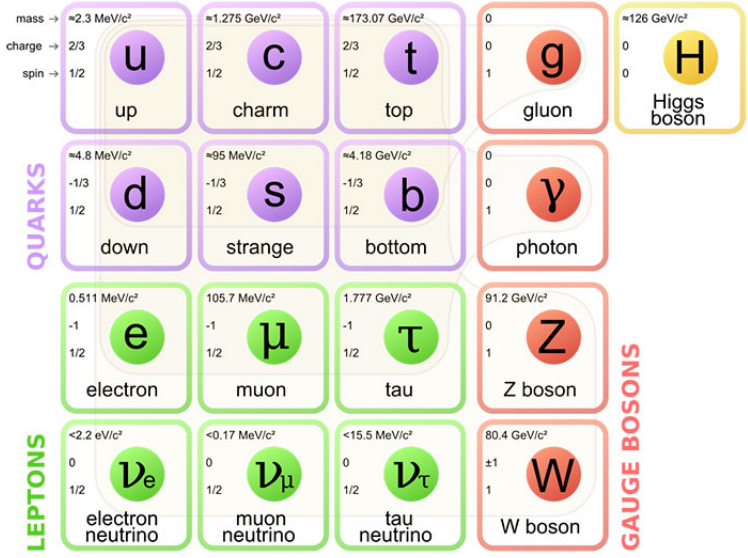
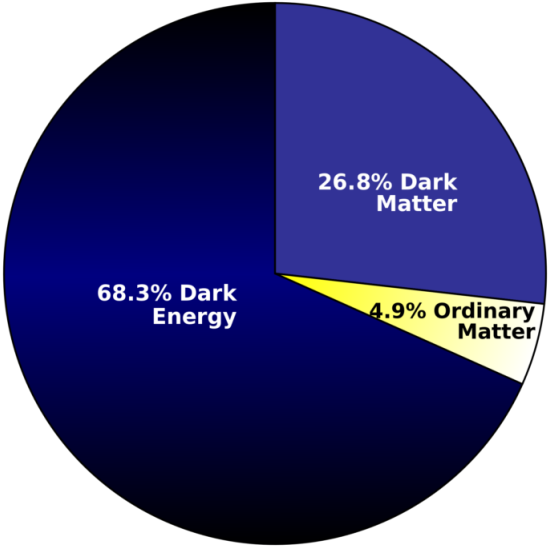
New Scientific Opportunities at the TRIUMF ARIEL e-linac

May 27, 2022

The Standard Model

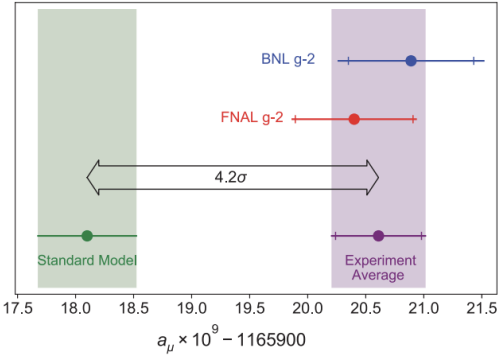


Here be Dragons



Anomalies Abound

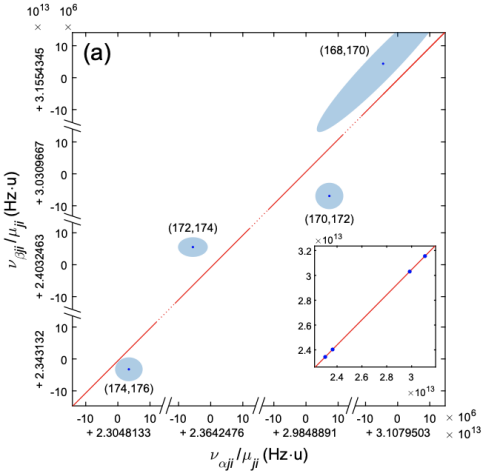
- $(g-2)_\mu$ anomaly (among other μ puzzles)
- Differences in standard model values between theorists calculations
- Could be indicative of BSM physics



PRL 126, 141801 (2021)

Anomalies Abound

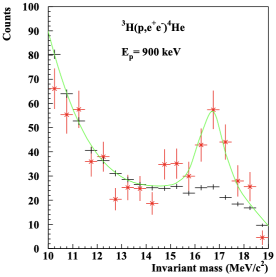
- King Plots show super ratios of isotope transition frequencies, anomaly in Ytterbium
- 3×10^{-7} deviation from linearity at 3σ level
- Potentially higher-order nuclear effects within standard model
- Could be described by bosonic force carrier
- new electron-neutron interaction?

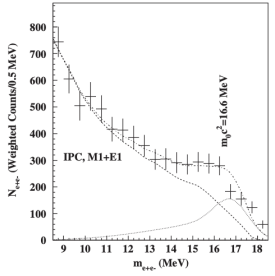


PRL 125, 123002 (2020)

Anomalies Abound

- Excess in e^+e^- invariant mass spectra in ^{8}Be and ^{4}He
- Corresponds to a mass of ≈ 17 MeV/c^2
- Seen at different angles and different experimental setups
- Proton-phobic boson could explain excess

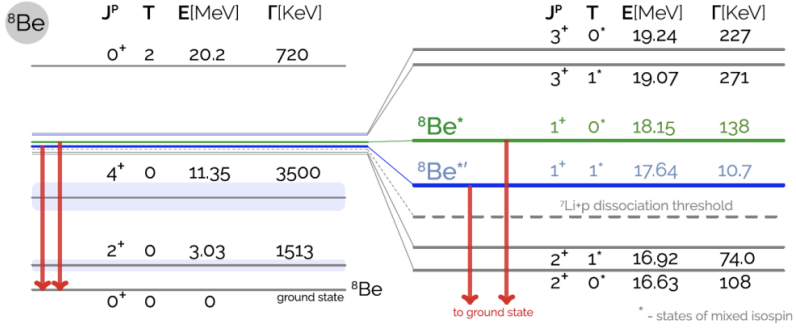




arxiv:1910.10459 and PRL 116, 042501 (2016)

Atomki Experiment

- ^{8}Be has several narrow states at higher energy
- Decay to ground state via electromagnetic transitions
- Produced from p+^{7}Li



Figures from https://arxiv.org/pdf/1707.09749.pdf

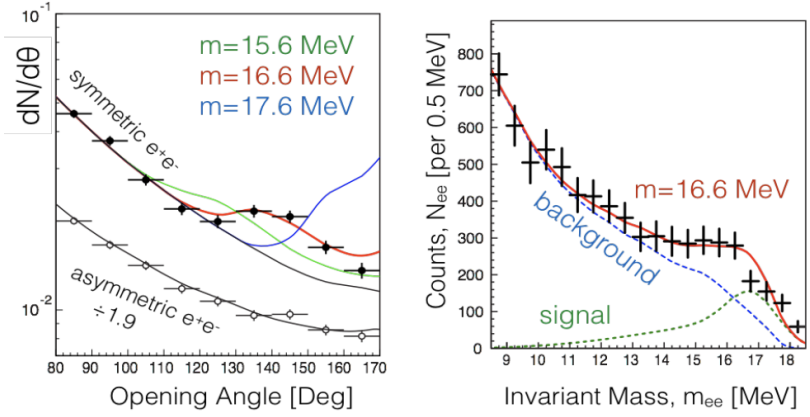
Atomki Experiment

- Decay modes of ^{8}Be
- Internal conversion of γ leads to e^+e^- pairs with measurable opening angle

Figures from https://arxiv.org/pdf/1707.09749.pdf

Atomki Experiment

- Signal rises and falls with proton beam energy
- Bump within acceptance, not edge effect
- Appears only for symmetric pairs, which is expected for intermediate massive particle
- Similar story for ^{4}He, different angle, same mass

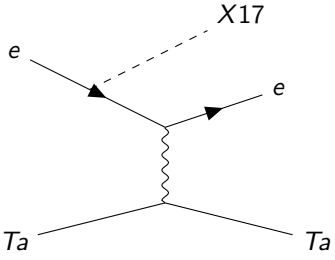


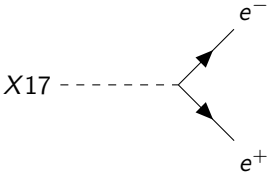
Figures from https://arxiv.org/pdf/1707.09749.pdf

X17 - Measurable in an Accelerator!

- Potential proto-phobic boson which couples to electrons
- Scatter low energy electrons on high Z target
- Spectrometer pair setup to measure e^+e^- pairs
- Can extract mass and coupling strength to electrons

X17 - Measurable in an Accelerator!



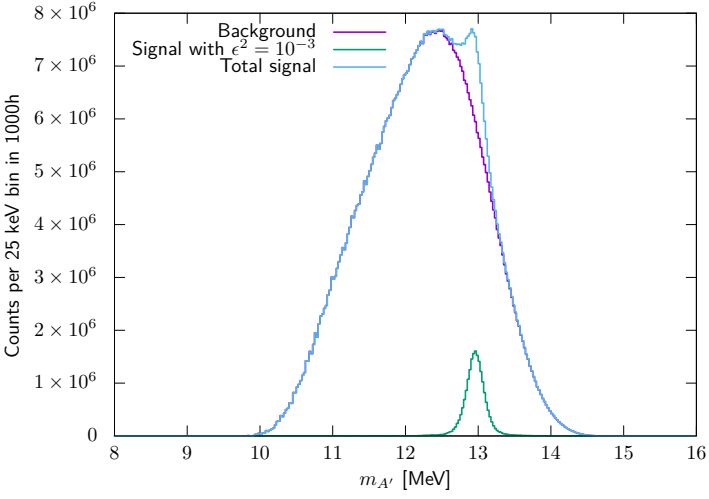


- Measure the produced e^+e^- spectrum and reconstruct invariant mass
- $m(e^+ + e^-) = m(X17)$

Background Processes

- Irreducible background
  - $X17 \to e^+e^-$ competes with $\gamma \to e^+e^-$
  - γ from scattering or radiative terms
  - e^+e^- pairs from γ scales with $\mathcal{L}$
- Random background
  - Any e^+ with beam e^-
  - Scales with $\mathcal{L}^2$
- Figure of merit for bump hunt
  - $\frac{S}{\sqrt{B}} = \frac{p_{sig}\mathcal{L}}{\sqrt{p_{irred}\mathcal{L}+p_{rand}\mathcal{L}^2}}$
  - Independent of $\mathcal{L}$ at large $\mathcal{L}$!

Bump Hunt


Background
Signal with $\epsilon^2 = 10^{-3}$
Total signal
Counts per 25 keV bin in 1000h
8×10^6
7×10^6
6×10^6
5×10^6
4×10^6
3×10^6
2×10^6
1×10^6
0
8
9
10
11
12
13
14
15
16
$m_{A'}$ [MeV]

DarkLight at ARIEL!

The DarkLight Collaboration

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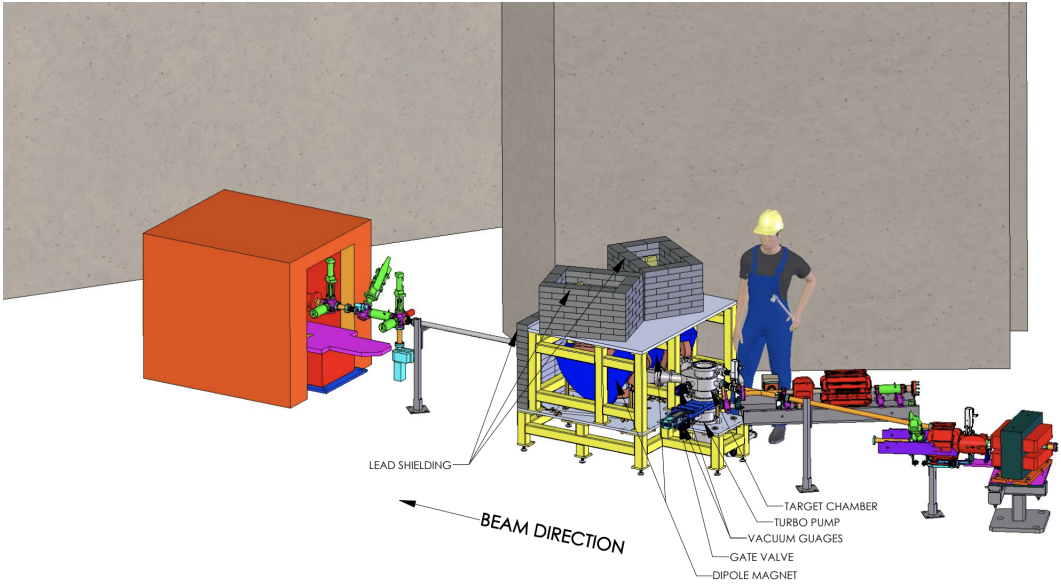
Co-Spokespeople: Jan Bernauer[b], Ross Corliss, and Richard Milner

DarkLight at ARIEL!

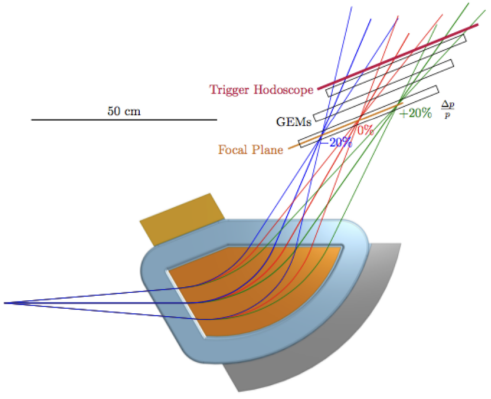


DarkLight Target and Beam

- 1 μm thick Ta disc target
- 150 μA beam, 30 MeV $\rightarrow$ 4 W heating
- Spinning target sufficient for cooling
- Pass-through configuration possible

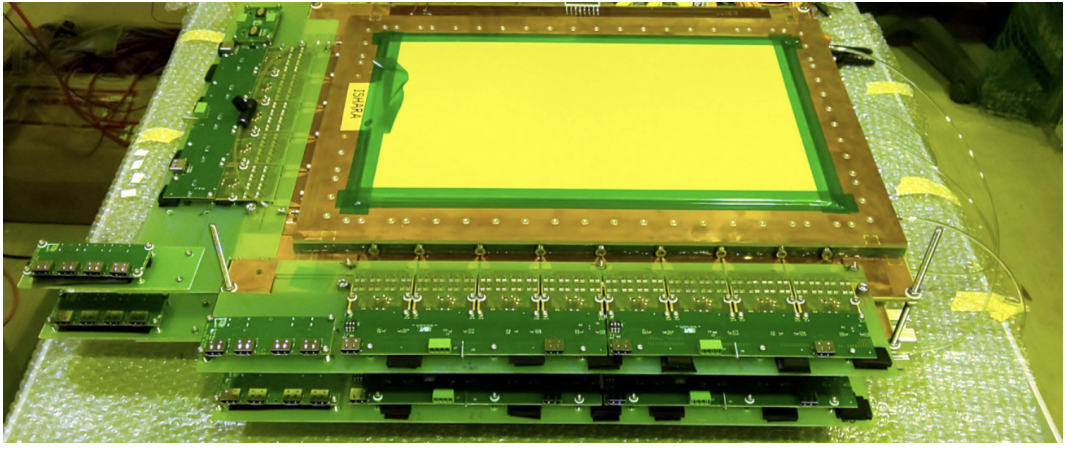
Spectrometers

- Up to 28 MeV central momentum
- $\pm 2^\circ$ in-plane acceptance
- $\pm 5^\circ$ out-of-plane acceptance
- ± 20 % momentum acceptance
- Single-dipole setup
- Final configuration and placement design work ongoing
- Mass resolution $\approx$ 120 keV



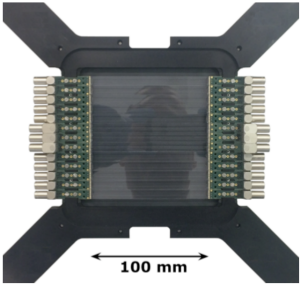
Tracking Detectors

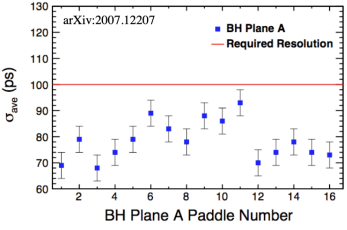
- 25×40 cm^2 triple-GEMs built by Hampton
- APV+MPD4 readout
- Planes constructed and already available



Trigger Hodoscope

- Trigger via segmented scintillator hodoscope
- Following design at MUSE:
  - 2 mm thick scintillator
  - Double-ended SiPM readout
  - Resolution <100 ps
  - Tested up to 8 mm wide and 15 cm long





NIMA 986, 164801 (2020)

Several Stages of Running

- Planned upgrades and expansions to the ARIEL hall
- Stage 0
  - Minimal changes
  - Run at 31 MeV near beam dump

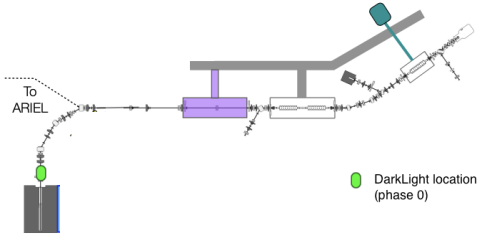
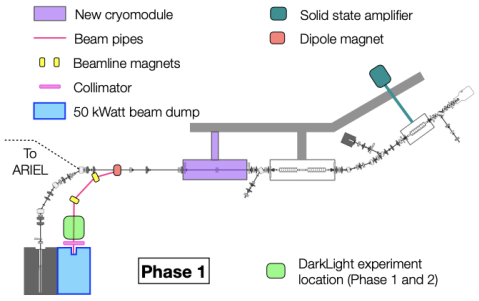


Photo from T. Planche's talk

Several Stages of Running

- Planned upgrades and expansions to the ARIEL hall
- Stage 0
  - Minimal changes
  - Run at 31 MeV near beam dump
- Stage 1
  - Single user mode
  - Up to 51 MeV



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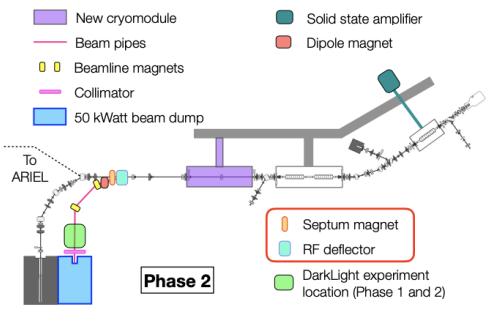
Several Stages of Running

- Planned upgrades and expansions to the ARIEL hall
- Stage 0
  - Minimal changes
  - Run at 31 MeV near beam dump
- Stage 1
  - Single user mode
  - Up to 51 MeV
- Stage 2
  - Multi-User mode
  - 51 MeV



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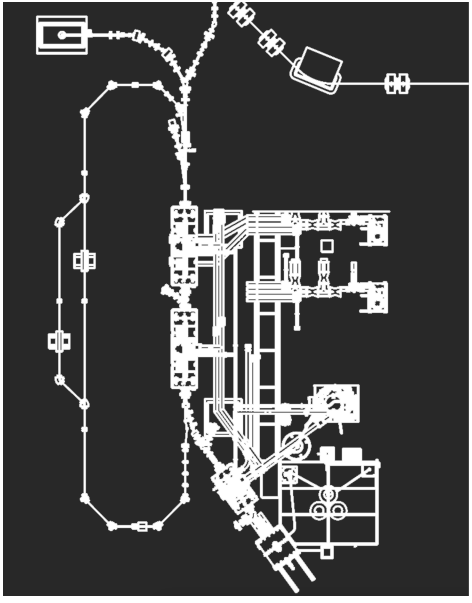
Several Alternative Stages of Running

- Planned upgrades and expansions to the ARIEL hall



Several Alternative Stages of Running

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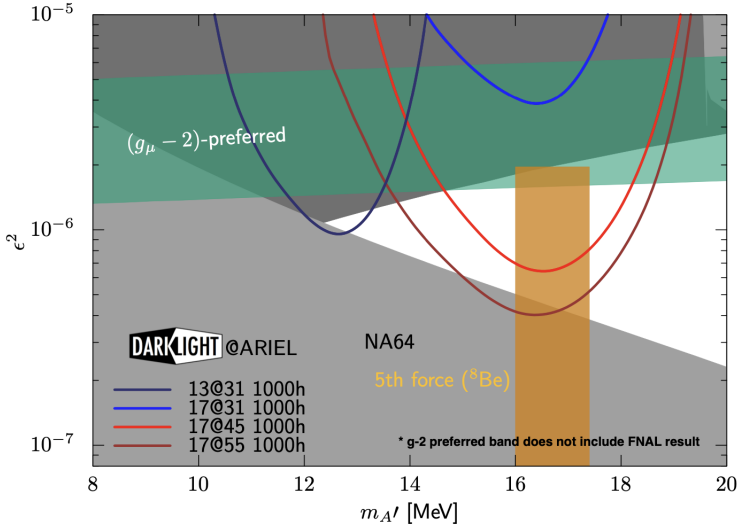
Several Alternative Stages of Running

- Planned upgrades and expansions to the ARIEL hall
- Stage 0
  - Minimal changes
  - Run at 31 MeV near beam dump
- Stage 1
  - Recirculation
  - Up to 51 MeV

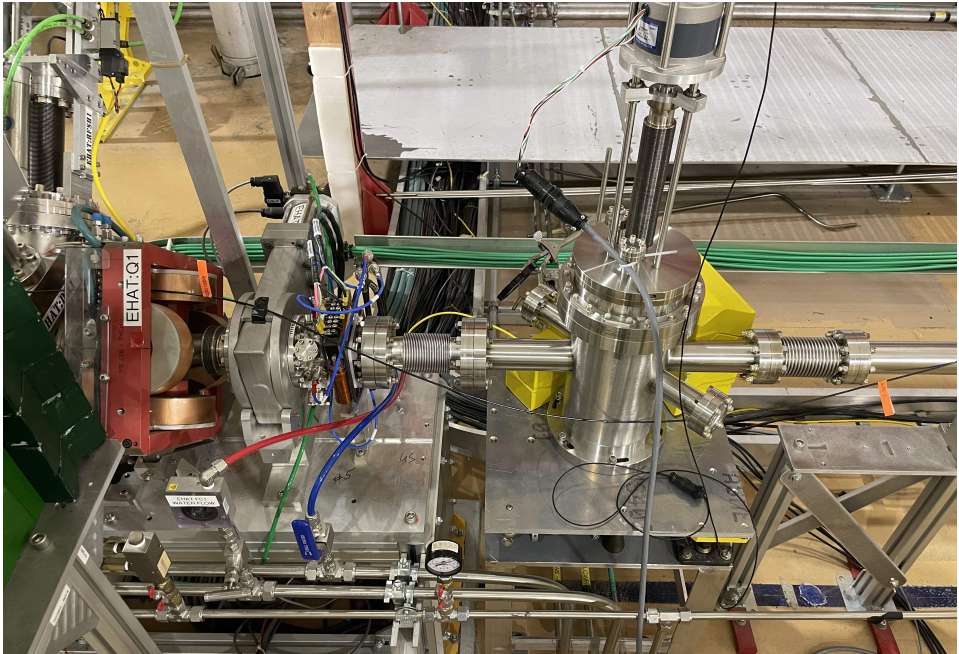
Several Alternative Stages of Running

- Planned upgrades and expansions to the ARIEL hall
- Stage 0
  - Minimal changes
  - Run at 31 MeV near beam dump
- Stage 1
  - Recirculation
  - Up to 51 MeV
- Stage 2
  - Additional Cryo module installed
  - Run DL simultaneously with ARIEL operation

Projected Reach

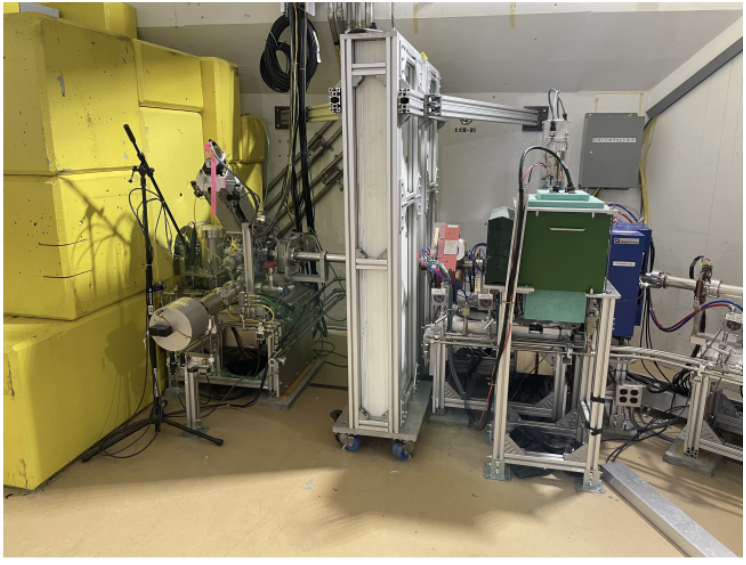


Current Status



Current Status

Test Run Upcoming



Moving near the beam dump in 2023. Photo Credit: T. Planche's talk.

Timeline

- Stage 0: Existing ARIEL Design
  - GEMs can be commissioned and available within 9-12 months
  - Can begin commissioning at TRIUMF $\approx$12 months after funding becomes available
  - Fall 2023(!)
- Second cryo-module design
  - Stage 1: additional cryo-module installed to reach 50 MeV beam
  - Stage 2: Septum + kicker to allow simultaneous running with ARIEL
- ERL upgrade path
  - Stage 1: Recirculation to reach 50 MeV beam, potential chicane to separate 1st and 2nd pass beams
  - Stage 2: Additional cryo target needed for beam to allow simultaneous running of DarkLight with ARIEL

Summary

- Many hints of BSM physics in a variety of experiments
- PP-EEC approved for 1300 h of beamtime
- Tuning the spectrometer design and placement
- Data taking in 2023